AN ASSESSMENT OF
AIR FORCE LOGISTICS COMMAND'S
PARTS REPLICATION PROGRAM

THESIS

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AFIT/GLM/LSMA/87S-68

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AN ASSESSMENT OF AIR FORCE LOGISTICS COMMAND'S PARTS REPLICATION PROGRAM

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the

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Master of Science in Logistics Management

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Preface

The purpose of this study was to investigate Air Force Logistics Command's parts replication program located at the Sacramento Air Logistic Center. The overall objective of the research was to determine the feasibility and application of the program to alleviate the high cost of contracting out the manufacturing of replacement parts. The program uses thermoplastic injection molded parts as replacements for metal parts. The research effort was designed to explore the applications of thermoplastic parts as a viable alternative to current metal parts. Hopefully, the results contained herein will provide added insight into the use of thermoplastics in making parts for Air Force aerospace systems. In writing this thesis, I have had a great deal of help from others. I am deeply indebted to my faculty advisor, Capt Dennis Hull. His innovative ideas, practicality, and sense of humor helped keep my endeavor in perspective. I am also appreciative of all those whom I interviewed for this study. All of the interviewees took time to answer all of my naive questions. Their willingness to share their experience and insights made my research almost painless. Finally, I wish to thank all of my friends for their concern and support.

Bernard L. Shalz

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Abstract

The purpose of this study was to examine the feasibility and application of Air Force Logistics Command's parts replication program to alleviate the high cost of contracting out the manufacturing of replacement parts. The program uses thermoplastic injection molded parts as replacements for metal parts.

The study found that the program had state of the art injection molding equipment. This included Computer Aided Design (CAD) equipment to design parts and molds and Computer Aided Manufacturing (CAM) equipment to help produce molds. Additionally, the process control system on the injection molder helped the operator control molding parameters and helped diagnose any problems during the molding process. Secondly, the study found that injection molded thermoplastic parts can replace certain metal parts on an airplane. However, these applications were limited to nonstructural parts. The inherent characteristics of thermoplastics gave them an advantage over metals. They were more easily fabricated using injection molding, more durable, corrosion resistant, and cost less to manufacture than current metal parts.

In addition, the study found the parts replication program at the Sacramento Air Logistic Center (ALC) to be in

its incipient phase. Currently, research is being conducted by the program on two parts, an enclosure for the ALE 40 chaff dispenser system and a fin for the 600 gallon drop tank used on the F-111. The program has also sent out a parts candidate questionnaire to the other ALC's in an attempt to find other parts which can be replaced with thermoplastics.

Since the program is not currently manufacturing parts, actual production costs were unknown. Without this information it was impossible to do a cost analysis of the program. As the program matures, further research is recommended to establish a cost analysis when the program is in its manufacturing stage.

AN ASSESSMENT OF AIR FORCE LOGISTICS COMMAND'S PARTS REPLICATION PROGRAM

I. Introduction

Background

One of the problems plaguing Air Logistic Centers (ALCs) is the high cost of structural replacement parts for airplanes going through depot maintenance (Reynolds, 1986). ALCs typically overhaul, repair, and restore relatively small quantities of a broad range of parts on airplanes going through depot maintenance (Hruskocy, 1985:22). According to Colonel Reynolds, Assistant For Reliability and Maintainability at HQ Air Force Logistics Command (AFLC), the cost of manufacturing a small number of replacement parts is exorbitant. He stated that current manufacturing techniques require that at least one hundred parts be produced even though only five may be needed. He further explained that many of these metal parts could be reproduced using thermoplastics (advanced non-metallic materials) (Reynolds, 1986). Similarly, Brigadier General John Slinkard believes that the defense industries' current manufacturing techniques are too expensive and incapable of handling small batch productions. He noted, "one way you get $650 ashtrays is to custom-make just three or four" (Chakravarty, 1985:80). Most of the U.S. defense contractors rely upon Detroit style automation for stamping out large production lots of identical items. This manufacturing technique is inflexible and does not lend itself to producing small batch lots economically (Bylinski, 1983:53).

Companies in Japan have found that flexible manufacturing systems have great potential as an inexpensive means of manufacturing small volumes of items. These systems, which incorporate computer aided design and manufacturing (CAD/CAM) along with robotic technology, have the ability to "turn out a product as efficiently as a production line designed to turn out a million identical items" (Bylinski, 1983:54). With the flexibility to have different products made on the same line at any time, the Japanese have found these automated systems to be five times more productive then their conventional counterparts (Bylinski, 1983:53-56). According to Dr. J. A. Decaire, an expert in flexible manufacturing, these systems are ideal for the production of a broad mix of small lot size parts. He states further that a flexible manufacturing system provides "significant quality and productivity improvements relative to the manually intensive assembly processes characteristic of present manufacturing practices" (Decaire, 1983:37).

Within the plastics industry, flexible manufacturing systems are currently incorporating injection molding machines to produce parts out of thermoplastics. The new computer integrated injection molders accentuate interchangeability and minimum human intervention during parts production. This gives the system a high degree of reproducibility and an ability to produce a wide range of products economically (Wigotsky, 1986:21). Allen Bradley, maker of electromechanical starters and controllers for industrial electric motors, has found a flexible manufacturing injection molding system the way to make complicated products. Bradley's system can produce parts rapidly in lot sizes as small as one (Bylinsky, 1986:65).

The CAD/CAM systems used in injection molding allow parts to be designed and fabricated to exacting specifications. The CAD system eliminates costly trial and error methods. The engineer can design molds appropriate to the thermoplastic being used and to the end-use of the product. It also allows the engineer to analyze the injection molding process on the computer to ensure that a part can be accurately produced. The CAM system controls the actual injection molding process . It speeds up production, cuts costs, and is responsible for producing consistently good quality parts each time (Frank, 1987).

Realizing the potential of flexible manufacturing systems, Air Force Logistics Command has initiated a parts replication program at the Sacramento ALC. AFLC believes that a parts-replication system may be the answer to producing small batches of replacement parts economically.

These parts would be made out of thermoplastics versus metal (Reynolds, 1986). The system incorporates computer-aided design and manufacturing(CAD/CAM) equipment already in use at the Sacramento ALC along with injection molding to produce the parts needed (Air Force Plans..,1986:55).

Specific Problem

This thesis will analyze the feasibility and application of the parts replication program to alleviate the high cost of contracting out the manufacturing of small lots of replacement parts.

Research Questions

The following questions need to answered in order to solve the specific problem of this research.

1. Have technological developments improved to the state that parts can be designed on a computer and then this design transferred to a computer aided manufacturing system to reproduce the original part using thermoplastics? If so, how does this system work?

2. How many parts on an airplane, such as the F-16, are capable of being made out of thermoplastics?

3. Can the other ALC's, with their CAD systems, transfer their design data to the computer manufacturing system at Sacramento to have parts made for them?

4. What is the impact of this system on the maintenance flow at the ALC?

The researcher chose to answer these questions through the use of a literature review and the surveying of experts involved in fields related to this program. A more thorough discussion of these techniques can be found in chapter III.

Scope and Limitations

This thesis concentrates on determining the application of a flexible manufacturing system program initiated by AFLC. The research is limited to the current proposed parts replication program which uses CAD/CAM along with injection molding to produce thermoplastic parts. It does not attempt to analyze other systems which are capable of producing metal or electronic parts.

Assumptions

Several assumptions were made by the researcher in compiling data for this thesis. An assumption was made that all persons surveyed were in fact experts in their respective fields. An expert was considered someone possessing specific knowledge in the areas addressed in this report. The second assumption made was that the experts chosen to be surveyed were actively involved in the parts replication program or had the background necessary to help answer the research questions.

Definitions

The following terms will be used during this research effort. Their specific meanings are provided.

Computer Aided Design (CAD) - process which uses a computer system to assist in the creation, modification, and display of a system. The computer stores design information and aids the engineer in examination of the design and factors influencing it (Kochan,1985:37).

Computer Aided Manufacturing (CAM) - the ability to control a portion or all of a manufacturing process through a computer (Kochan,1985:37).

Detroit Style Automation - a manufacturing technique for producing mass quantities of identical parts. The part being produced is processed via a conveyor from machine to machine. Each machine is dedicated to a single task and must either be replaced or rebuilt at the time of a product change (Bylinski, 1983:54).

Flexible Manufacturing System (FMS) - the ability of computers to coordinate design, manufacturing, and management of a product from conception to its finished state (Gilbert, 1986:54).

Injection Molding - a process in which thermoplastic material in pellet or powder form is fed through a hopper at the rear of a heating cylinder. The material is then heated until it reaches a molten state. Under hydraulic pressure, the material fills a mold cavity. The material is then cooled in the mold where it takes its final shape (Crosby, 1972:3).

Thermoplastic - a plastic used in injection molding which becomes soft when heated and then hardens as it cools (Crosby, 1972:41).

Summary

This chapter presented an overview of the spares replacement problem facing depot maintenance. How AFLC plans to solve this problem through a parts replication program which incorporates CAD/CAM equipment with thermoplastic injection molding was explained. In the following chapter, the researcher develops the specific concept of flexible manufacturing as it relates to thermoplastic injection molding. This was accomplished by reviewing the literature written on these subject areas. Chapter III contains the methodology used in this research study, including an examination of the use of literature review and surveys. The results of the literature and surveys are reported in chapter IV. Finally, chapter V has conclusions and recommendations for further study.

II. Literature Review

Background

The parts replication program at the Sacramento ALC incorporates several aspects of state of the art technologies in flexible manufacturing. The literature review was used to explain the equipment used in the parts replication program. This included the injection molding machine, the CAD/CAM system used with the machine and the CAD/CAM system used to make the molds for the injection molder. The literature review also explores the properties of thermoplastics and their applications. The review of literature on thermoplastics attempts to find applications of thermoplastics for airplane parts. The researcher found that the use of thermoplastics in the aerospace industry is rather a new frontier. A majority of the literature dealt with applications of thermoplastic parts within the automobile industry. This information was considered important because applications in the automobile industry may be studied and used as a basis for applications in the manufacturing of airplane parts.

Injection Molding System

"An injection molding machine is a machine for the converting, processing, and forming of raw plastic material of powder, pellets, or regrind into a part of desired shape and configuration. The process of injection molding consists of heating plastic material until it melts, then forcing this melted plastic into a mold where it cools and solidifies" (Flickinger, 1986:39).

Injection molding has the advantage that molded parts can be manufactured economically in unlimited quantities with little or practically no finishing operations (Rosato, 1986: 3). The injection molder can repeatedly mold parts to tight tolerances (Rosato, 1986: 4). There is a three step process involved in molding thermoplastic parts.

The first process is raising the temperature of the plastic to point where it will flow under pressure. This is done by simultaneously heating and masticating the granular solid (thermoplastic pellets) until it forms a melt at an elevated and uniform temperature and viscosity. This step is accomplished in the cylinder of an injection molding machine which is equipped with a reciprocating screw. This part of the machine provides the mechanical workings needed to melt the plastic and control its flow (Rosato, 1986: 9).

The second process is allowing the plastic to solidify in the mold. The mold is mounted in a hydraulic clamping unit. This portion of the injection molding machine provides the motion and force to open and close the mold and to hold the mold closed with force during injection. (Flickinger, 1986:39). The liquid, molten plastic from the injection cylinder is transferred through various flow channels into the cavities of a mold. Here it is shaped into the desired part by the confines of the mold cavity (Rosato, 1986: 9).

The third process is opening the mold to eject the plastic. This is done after keeping the material confined under pressure while removing the heat from the molten plastic. The plastic solidifies and freezes permanently into the desired shape (Rosato, 1986: 9).

The time required for this rapid conversion of thermoplastic pellets into a finished part is limited by only two factors. One, the rate at which the thermoplastic can be brought to its processing temperature (usually at or above its melting temperature). This varies among the different thermoplastics due their chemical characteristics. Two, the rate at which the heat can be removed from the material once the forming process is completed. This varies according to the thermoplastic used and the size of the mold (Krone, 1986:61).

A CAD/CAM system used in conjunction with the injection molding machine allows parts to be designed and fabricated to exacting specifications. The CAD system is able to simulate all phases of the injection molding process. It provides both flow and cooling analysis. The computer provides comprehensive information on the velocity, temperature, and pressure throughout the flow domain. With the ability to analyze the process on the computer, the engineer can ensure that a proposed part can be accurately produced (Gosztyla, 1986a:344). In addition, the CAD system also helps reduce rework costs. The computer is able to help the engineer analyze the mold prior to actual making it which increases the probability that the mold will run successfully the first time in the press (Gosztyla, 1986a:348).

CAD/CAM System for Building Molds

Once a mold has been analyzed on the injection molders CAD system and selected for use, it can be reproduced on another CAD/CAM system which will operate and control the machining process. The geometric data from the injection molder CAD system is sent to the machining CAD/CAM system. CAD/CAM technology facilitates the use of numerically controlled (NC) machining tecnnology in the fabrication of the the molds themselves (Gosztyla, 1986b:318). The CAD system provides the data to the NC machines which control complex machining operations which create highly reproducible tolerances in the molds with minimal human operation (Wisnosky, 1980:27). With this equipment, much more of the mold can be cut in single setups at a single machining center. This reduces the number and complexity of manual setup operations. This system allows the three-dimensional product models designed by the engineer to be placed in the CAD data base. The CAM system automatically generates tool paths from the data base which reduces the amount of effort spent in defining section views, calculating pickup points, and the like. The availability of graphic tool path generation and verification eliminates the manual data entry steps and proofing cuts previously required on the shop floor (Gosztlya, 1986b:317).

The CAD/CAM system eliminates previous manual defects in making molds. The complex geometric shapes such as sculptured surfaces and blending radii are totally described in the data base, and thus not subject to ambiguities in mechanical drawing interpretation. By utilizing NC in moldmaking, the conformance of the mold core and cavity to the part's requirements is virtually guaranteed (Gosztlya, 1986b:318).

The ability of CAD/CAM to speed up the plastic part and mold design process, the mold manufacturing process, and the start-up and debugging process makes it an invaluable aid in economical injection molding (Gosztlya, 1986b:319).

Thermoplastics and Their Applications

Various thermoplastics exist in the commercial market. The intent of the literature review was to examine the characteristics of the commercially available thermoplastics and to discover their applications in producing airplane parts. Many of the thermoplastics studied were used in the automobile industry. The researcher believed that the use of thermoplastic parts in an automobile may be extended to similar applications on an airplane. Even though not as numerous, the researcher did find some current applications of thermoplastics in the aerospace industry. The characteristics of thermoplastics and their applications in both the automotive and aerospace industries follows.

According to James L. Thorne, no plastic is as strong as steel. In addition, none have the useful temperature range of ceramics or metals. No plastic can match the abrasion resistance of porcelain and none can match the fire retardancy of asbestos. However, Throne believes that there are many applications where these extreme conditions are not needed and plastics can be substituted readily (Thorne, 1979:21-23).

There are a variety of engineering thermoplastics currently available on the commercial market. An engineering thermoplastic is a material that can be used in designing parts with critical endurance specifications. For example, there are thermoplastics such as ABS (acrylonitrile butadiene styrene), PC and PEEK (polyetheretherketone). There are thermoplastic blends such as epoxy and urethane. There are thermoplastic fibers or fillers such as carbon filler. A few of the better known engineering resins are ABS, ploycarabonates, ploysulfones, ployimides, and ploybenzimidazoles (Moseley, 1986:49).

Thermoplastics derived from the condensation polymerization of aromatic molecules can be used under temperatures of 500 F. These include thermoplastics with industrial names such as UDEL, RADEL, ULTEM, TORLON, XYDAR, and PEEK (Moseley, 1986:50). Polysulfones (Udel and Radel) from Union Carbide are used when the parts made from these thermoplastics are exposed to a variety of solvents and high temperatures. Although it has limited toughness, General Electric's Ultem is extremely fire retardant and can withstand a variety of harsh environments. Amoco's Torlon is a ploymide-containing aromatic condensation polymer. It has such a high temperature distortion that it has been used as a matrix resin by Polimotor Research in the manufacture of a composite test engine. Dart's Xydar has such a high heat distortion temperature that ovenware is being produced from it. PEEK holds great promise in the aerospace industry because it holds its properties under conditions of both high temperature and high moisture (Moseley, 1986:51).

Thermoplastics made out of polymer fibers have high strength characteristics. The great advantage of a polymer is its strength with little weight. However, polymers such as polyethylene fibers melt at 148 C and are not useful for high temperature applications (Wittcoff, 1987:156). Recently developed thermoplastics made from liquid crystal polymers can be injected molded at about 420 C. It retains stiffness up to 400 C and negligible creep at 100 C. Liquid crystal polymers have several advantageous characteristics: low shrinkage due to polymer alignment, low warpage, low creep, high heat distortion point (300-400 C), chemical resistance, chemical inertness and toughness (Wittcoff, 1987:158).

Other engineering thermoplastics include polycarbonates (PCs). These materials are designed to replace metal and glass in applications demanding strength and temperature resistance. They offer advantages of light weight, low cost, and ease of fabrication (Sikdar, 1987:112). PC molded materials are tough, dimensionally stable, and transparent. PCs are self-extinguishing and resistant to salts and oxidizing agents. However, they are susceptible to stress cracking and attacks by solvents, weak acids, and alkali. They also have low abrasion resistance (Sikdar, 1987:116).

The automotive industry has found advantages to replacing metal parts with plastics. The plastic parts cost less. They also enhance performance (Pullin, 1986:9). For instance, injection molded thermoplastic parts are used to make bumpers on the Ford Tauras, the Mercury Sable and the Astrovan (Cassidy, 1986:28). Thermoplastic acrylic windows are used in the Pontiac Fiero. The injection molded window is coated for abrasion resistance. It offers toughness, easy styling, and easy installation (SPEs..,1986:44).

New engineering thermoplastics are also being used in the automotive industry. Torlon has been used in building car engine pistons by the students at the Mechanical Engineering Department of Western Michigan University. A thin ceramic coating on the crown acts as a heat shield and prevents the plastic from melting. The ceramic protects the plastic piston from exposure to temperatures in the

2000 F range which is well beyond the limit of engineering plastics (Cassidy, 1986:28).

Also in the automotive industry a Lomod family of flexible engineering thermoplastics has been developed by GE Plastic to bridge the gap between rubber, other elastomers and high performance engineering thermoplastics. These low-modulas semicrystalline materials combine the inherent high strength and processibility of thermoplastics with the flexibility and impact resistance of thermosetting rubbers. These thermoplastics come in twelve grades differentiated by stiffness, heat resistance and flame retardance. They are able to work in temperatures ranging from a minimum -30 C to maximum temperatures of 90 to 120 C (Flexible..,1987:9).

Although stiffer then rubber, the Lomod family of thermoplastics have engineering properties that allow them to be used in traditional rubber application areas. These thermoplastics can be used in parts that require demanding flexibility with improved heat and chemical resistance. The low temperature ductility, high temperature capabilities and high flexural fatigue resistance of these materials make them suitable for molded parts and coating in aggressive or exposed environments (Flexible..,1987:9).

The broad range of stiffnesses allows engineers greater design flexibility. The high strengths of these materials allow parts to be designed with thinner walls without compromising mechanical performance. Because of their good flow characteristics in injection molding, the result is faster production cycle times and lower material consumption. This enables the processor to improve quality and reduce parts cost (Flexible..,1987:9).

Also used in the automotive industry are polyarylates such as those developed by DuPont. A polyarlylate is a high-molecular-weight organic polymer classified as a type of amorphous polyester (DuPont.., 1986:33). Polyarylates are heat-resistant high performance thermoplastics. DuPont is promoting its use in the manufacturing of automobile body panels (Cheaper.., 1986:36). The DuPont company has reported the discovery of a process for making super-tough and heat-resistant polyarylate resins at a price 20 percent lower than current methods. DuPont has already molded developmental thermoplastic doors, fenders, and bumpers (DuPont.., 1986:33).

DuPont's Arylon polyarylate is cited for high strength, elevated temperature stability, weatherability, and processing ease. According to DuPont it has the potential to replace metal, glass and other materials in the automotive industry. Advantages of the material are its light weight, corrosion and dent resistance, and longer life than steel. It has the ability to be injected molded for large components. In these applications its combination of high temperature resistance, dimensional stability, and flame resistance could be applied to parts on an airplane (Cost-effective.., 1986:82).

In the aerospace industry thermoplastics are receiving more attention as manufacturers attempt to replace metallic parts with more durable and cheaper plastics. For instance, molded PEEK plastics can be used instead of aluminum on cheek fairings for Boeing's 757-200 jet planes. The original aluminum fairings cost $500 each; substituting the PEEK fairings lowered the cost of the part by 90% and reduced its weight by 30% (Slakter, 1987:13).

In another example, polyarylene sulfide polymers developed by Phillips are believed to be suitable for high temperature performance demanded in fighter aircraft. According to James O'Conner, supervisor for thermoplastic composites at Phillips Research Center, PAS1 (a crystalline form) is suitable for structural components at temperatures up to 250 F and up to 450 F for nonstructural uses. The amorphous form, PAS2, has temperature limits of 325-400 F for structural components and 520 F for nonstructural parts. Phillips is also working on a more advance version called PAS B for structural use at 500 F (Kemezis, 1986:7).

Phillips has also developed a new injection molding compound called Ryton. High molecular weight Ryton polyphenylene sulfide (PPS) is combined with 30 percent by weight short carbon fiber reinforcement. A jet engine thrust reverser cascade has been injection molded using the new compound. The new compound "augments the high strength and stiffness, chemical and inherent flame resistance, and thermal stability of Ryton PPS with electrical conductivity, lubricity and resistance to high temperature humidity environments contributed by the carbon fiber" (Ryton.., 1987:153).

Imperial Chemical Industries is working on a aromatic polymer composite (APC) called HTA for use in the aerospace industry. An amorphous version of HTA will perform at temperatures up to 482 F. APC HTX, the crystaline form, is more solvent-resistance and can operate at temperatures as high as 356 F (Kemezis, 1986:7).

Another engineering thermoplastic, Xydar, is being evaluated for use in manufacturing airplane parts. It has been injection molded into a jet engine component because of its excellent strength, chemical and heat resistance, flame retardance and low smoke properties. Another injection molded Xydar component for a commercial aircraft is being evaluated because of the new liquid crystal polymer's exceptional flame retardance, high temperature strength, solvent resistance and easy processability (Lenz, 1986:204).

Summary

Injection molding manufacturing allows for the fabrication of parts to exacting specifications without human intervention or error. The use of CAD/CAM equipment with the ejection molder helps the engineer design high quality parts. It also helps the engineer analyze any problem with the molding process before any parts are actually produced. In addition, CAD/CAM equipment in the use of mold making allows for accurate molds to be produced. Finally, thermoplastics are easily fabricated, more durable, corrosion resistant, and less expensive than metals.

III. Methodology

Research Approach

Because the parts replication program is such a novel approach to solving depot maintenance spares programs, existing knowledge was insufficient for the use of comprehensive survey questionnaires that could then be analyzed by various statistical techniques. Therefore, two approaches were used to answer the research questions previously stated in Chapter I. The first approach was a literature review to provide background information. The second approach was interviewing experts familiar with the application and feasibility of the parts replication program.

Literature Review

A review of all appropriate literature was conducted. This included current trade journals, periodicals and books explaining the use of flexible manufacturing systems, CAD/CAM systems, and thermoplastics. The literature review provided background information and helped answer research questions in the following manner:

First, it established the current state of technology in industry regarding the use of computer aided design and manufacturing equipment. This helped answer the question relating to the flexibility of this manufacturing technique.

It also showed the applications of this technique to depot maintenance. (Research question 1 and 4)

Second, the literature review established the use of thermoplastics parts in airplanes. This helped answer the question of how many parts in an airplane can actually be reproduced using thermoplastics. (Research question 2)

Interviews

The need for in-depth knowledge of experts requires the use of interviews. Interviews typically allow for more complex information than questionnaires because the interviewer can ask for explanations. Two techniques for conducting interviews are in person or by phone (Fink, 1985:13;20). Because of the close proximity of the interviewees, Wright Patterson AFB and Cincinnati Milacron, the researcher used personal interviews. The purpose of the interviews was to benefit from the expertise of the Air Force's and the private sector's involvement in flexible manufacturing and thermoplastics. The interview questions were unstructured in order to let the interviewees share their insights and knowledge related to the parts replication program.

Interviews were conducted with experts in the fields of computer aided design and manufacturing along with thermoplastic engineers. Managers at Cincinnati Milacron are leaders in the application of CAD/CAM systems for industrial use (Reynolds, 1987). Their knowledge was used to establish the feasibility of the AFLC's intended parts replication program. Engineers at AFWAL are experts in the use of thermoplastics. Their knowledge was used to establish the possible uses of thermoplastic parts on airplanes. (Research questions 1 and 2)

Other interviews were conducted with engineers familiar with the F-16 program. Several parts on the F-16 are being studied to determine if these parts can be reproduced using thermoplastics and computer aided manufacturing techniques. This was used to indicate the types of parts on an airplane that are applicable to the parts replication program. (Research question 2)

Finally, interviews were conducted with members of the AFLC parts replication program. These experts knew the the capabilities of the other ALC's. Their knowledge helped answer the questions about the other ALCs' CAD systems. It also helped in assessing the compatibility of the ALCs' CAD systems with the main computer at the Sacramento ALC. Additionally, their knowledge of the program was used to assess the impact of this system on the maintenance flow at the depot. (Research questions 3 and 4)

Summary

This chapter discusses the approaches that were used to answer the research questions. Since the parts replication program is such an innovative approach to solving the depot maintenance spares problem, two techniques are used to gather data, a literature review and interviews. The results of the literature review and interviews are reported in chapter IV.

IV. Analysis

This chapter provides an analysis of data collected from the literature review and various interviews. In addition to providing answers to the research questions, the interviews provided interesting insight into the future of thermoplastics in the aerospace industry and new processing techniques beyond injection molding. This information will be provided Chapter V. Each research question presented in Chapter I is sequentially addressed.

Research Question One

> Have technological developments improved to the state that parts can be designed on a computer and then this design transferred to a computer aided manufacturing system to reproduce the original part using thermoplastics? If so, how does this system work?

The literature review in Chapter II provided abundant evidence that certain airplane parts can be reproduced using thermoplastics. These parts can be designed on a CAD system and then a mold can be made from the design on numerically controlled milling machines.

Chris Frank, who is currently managing the parts replication program at the Sacramento ALC, explained that 2 million dollars in state of the art equipment is being used in the program. A 1500-ton injection molding machine from Cincinnati Milacron is installed at the Sacramento facility. Included with the injection molder is a process control system. This system allows for a high degree of accuracy by continually producing high quality parts. The system enables a processor to make adjustments to the manufacturing process. The system also enables the machine to make minute changes in the processing to account for temperature variations, pack and hold pressures, and cooling time for curing. The process system provides the operator with a visual display of all functions on the machine as it manufactures a part. It also provides diagnostics if problems arise during processing. Once a process is established that produces the quality parts needed, the system loads the processing parameters onto a cassette. This processing data can be reloaded at a later date to remanufacture another batch of parts. The cassette may also be used on another Cincinnati Milacron injection molder to reproduce exacting processing parameters (Frank, 1987).

In addition to the injection molder and process control system, the Sacramento ALC has installed a Unigraphics CAD system on a VAX 630 microcomputer. This system allows the engineer to design parts and the mold necessary to reproduce the part. The CAD also has a master link to the shop floor numerically controlled (NC) 4-axis milling machines. Therefore, once a mold has been designed on the CAD system, the data to make the mold is sent down to the milling machine computer. The milling computer then controls the tool paths for making the mold. The milling machine is able to produce a mold to the exact specifications of the designer (Frank, 1987).

Mr. Frank also explained that the molds built at the Sacramento facility are different than those used in industry. In the injection molding industry, complicated single piece molds are often built. for example, if a box were being molded in which four posts were needed inside the box, a single mold would be built and the steel post mold automatically extracted by a machine. This would require a very complicated and expensive single-piece mold. In industry, this cost would be amortized over millions of identical parts. Therefore, the cost of such a mold is warranted. Mr Frank, stated that such a mold would be too expensive because their program is expecting to make "one thousand, two thousand or up to ten thousand parts." Therefore, the parts replication program makes segmented molds. Mr Frank further explained that segmented molds work very well for parts which have complex shapes such as undercuts, indents or holes. Segmented molds require that once a part is made the segments must be extracted by hand and then reset for the next part. This lengthens the cycle time between the parts being made. Even with more time being spent between making parts and the labor costs involved, segmented molds are an inexpensive way to produce thousands of parts versus an expensive single piece mold to produce millions (Frank, 1987).

In summary, the parts replacement program has many of the attributes found in a flexible manufacturing system. The CAD system allows engineers to design parts and the molds necessary to make the parts. The master link provides the interface between the CAD system and the NC milling machines to produce the molds to exacting specifications. The molds must be mounted through manual labor. Although this step can be accomplished by robots, the cost of such a set up is too expensive for the work being done at the Sacramento facility (Frank, 1987) In addition, manual labor is required to extract and reset the mold segments. Once again the cost of a single-piece mold is too expensive to warrant its use for the rather small part batches that the parts program will produce (Frank, 1987). Finally, the process control on the injection molder provides the operator with the diagnostics to trouble shoot any problems with the production process. It also allows for processing parameters to be loaded onto a cassette for later production runs or the processing data could be transferred for use in another Cincinnati Milacron injection molder.

Research Question Two

> How many parts on an airplane, such as the F-16, are capable of being made out of thermoplastics?

As mentioned in the literature review, thermoplastics are receiving attention within the aerospace industry as less expensive and lighter alternatives to metallic parts.

for instance, molded PEEK plastics are used instead of aluminum on cheek fairings for Boeing's 757-200 jet planes (Slakter, 1987:13). A jet engine thrust reverser cascade has been injection molded using Ryton (Ryton..., 1987:153).

Mark Elsass, a plastics engineer with Cincinnati Milacron, believes that thermoplastic injection molded parts do have limited use as airplane parts. He states that injection molded parts do not have the tensile strength needed to be used as structural components. However, thermoplastics can be used in making parts such as electrical connectors. They have a definite advantage over metallic counterparts because of their chemical resistance, heat and electrical properties, good insulating qualities, strength, and ability to operate in harsh environments (Elsass, 1987). Ken Vincent, a program manager at PRAM (Producibility Reliability Availability Maintainability), stated that thermoplastic connectors are being used in the A-10, FB-111, and F-16. These connectors are light weight saving 32% over the standard metallic connectors. They are corrosion resistant and very durable which gives them the ability to withstand over 1000 mating cycles (Vincent, 1987). Mr Elsass also explained many parts within the cockpit such as enclosures and panels could be made out of thermoplastics (Elsass, 1987).

Captain Mike Fortson, an advanced composite engineer with Air Force Wright Aeronautical Laboratories (AFWAL), explained that injection molding is an inexpensive and easy way to process airplane parts. Nevertheless, he pointed out that injection molded thermoplastics do not have the strength needed for use as structural parts due to the discontinuous chopped fibers. He foresees using injection molded parts for flap trailing edges, nonstructural doors which are not subject to stress loads, equipment racks, seats, electronic enclosures, and connectors (Fortson,1987).

On the F-16, avionic enclosures are being evaluated as thermoplastic candidates. Captain Larry Lee, a materials engineer at AFWAL, stated that the F-16 currently uses metal avionic enclosures. These enclosures are heavy, costly, difficult to fabricate and repair, and also subject to corrosion. Three enclosures are being evaluated and if they are found suitable, a total of seven enclosures could be made out of thermoplastics. The three enclosures being studied are the Avionic Video Tape Recorder (AVTR), Missile Remote Interface Unit (MRIU), and the Central Interface Unit (CIU). The cost and weight savings are given below.

	Cost		Weight	
	Metal	Plastic	Metal	Plastic
AVTR	$61.80	$44.50	.51 lb	.25 lb
MRIU	$428.20	$58.80	1.41 lb	.99 lb
CIM	$1151.00	$546.65	9.51 lb	6.32 lb

Captain Lee explained that the thermoplastic enclosures are superior to the metal enclosures. The maintenance inspection and painting of the enclosures would be eliminated. Replacement cost because of corrosion would be eliminated. In addition, the thermoplastic enclosures are lighter and less costly (Lee, 1987).

At the Sacramento parts replication program two parts are being prototyped and analyzed. The first part is a thermoplastic enclosure for the ALE 40 chaff flare system which is used on the A-10, F-16 and B-52. Mr. Frank estimates that a thermoplastic enclosure is more durable and reduces the price from $250 to $60 versus the current metal enclosure. The second part is a fin for the 600 gallon drop tank used on the F-111. This fin is easily fabricated by injection molding and costs $250 versus the current $2500 fin (Frank, 1987).

In conclusion, all of the experts interviewed pointed out that injected molded thermoplastic parts, because of their discontinuous fibers, can not be used as structural components. They did explain that thermoplastic parts can be used in nonstructural applications. The examples include electronic enclosures, connectors and access doors. The advantage of these parts are durability, lightweight and cost savings.

Research Question Three

> Can the other ALC's, with their CAD systems transfer their design data to the computer manufacturing system at Sacramento to have parts made for them?

According to Chris Frank, manager for the parts replication program, a proposal is being studied to provide the other ALC's with the capability to transfer their design data to the Sacramento ALC. He stated that the other ALC's will be able to design parts on their CAD systems and send the design data to the parts replication computer. Once the data has been transferred, the part will be prototyped at the Sacramento facility. If the prototype is acceptable, Mr Frank explained that, through a manufacturing memorandum of agreement, the Sacramento facility could make a batch of parts for any of the ALC's. He further explained that his shop could send the mold and injection molding process parameters to the other ALC's. By doing this the other ALC's could go to local injection molders and have their parts manufactured (Frank, 1987).

Mr. Frank also foresees any ALC with a large electronics work load purchasing their own smaller injection molder. He believes that a 300 or 500 ton injection molder could be used by the other ALC's to manufacture their own electronic enclosures (Frank, 1987).

Research Question four

What is the impact of this system on the maintenance flow at the ALC's?

Chris Frank at the parts replication program explained that thermoplastic injection molded parts would have little effect on maintenance flow at the ALC's. He stated that the parts replication program is being used to find parts that can be more easily fabricated and produced at a lesser cost than current manufacturing techniques. He also explained that the program is attempting to take advantage of thermoplastic characteristics. They are light weight, more durable and corrosion resistant as compared to metal parts (Frank, 1987).

Captain Fortson, an advanced composite engineer at AFWAL, agrees. He stated that injection molded parts have a somewhat limited application in the airplane. Because of their discontinuous fibers, they can't be used as structural parts. However, they can be used as replacements for metal enclosures and connectors. He explained that as a plane goes through depot maintenance the metal enclosures and connectors could be replaced with thermoplastic parts. This would not alter the flow of planes through depot maintenance (Fortson, 1987).

Mr Frank also explained that although parts can be easily manufactured through injection molding, all of the thermoplastic parts must go through testing before being placed on an airplane. Therefore, if a part is no longer being made or may be replaced by thermoplastics, it must go through extensive testing before being accepted. Because of the time required for testing, a thermoplastic replacement would not speed up the flow of a plane through depot maintenance (Frank, 1987).

Summary

This chapter focused on answering the research questions in order to analyze the feasibility and application of the parts replication program. From the literature review and interviews it was found that airplane parts could definitely be fabricated using thermoplastic injection molding. The Sacramento facility has state of the art CAD equipment for designing parts and molds. It also has CAM equipment for making molds. In addition, the injection molding machine has a process control system that allows the operator to control all phases of the molding process and provides diagnostics if any problems arise. The system also stores the processing parameters to be used at a later date or transferred to another injection molding machine.

The literature review and interviews also gave current examples of thermoplastic parts being made foı airplanes. All of the experts agreed that thermoplastic injection molded parts could not be used in structural applications. However, they did explain that thermoplastics could be used as replacements for such items as metal electronic enclosures, connectors, and fins on a F-111 drop tank. The literature review and experts lauded the advantages of thermoplastic parts over metal. The injection molded thermoplastic parts were more easily fabricated, more durable, corrosion resistant and less costly.

Chris Frank, manager of the parts replication program, explained that the other ALC's will be able to design their own parts and then have the Sacramento facility manufacture the mold and prototype the part. He also stated that his shop could transfer the mold and processing parameters so that the ALC's could find local manufacturers.

Finally, the experts interviewed felt that the parts replication program would not alter the flow of planes through depot maintenance. They explained that as planes went through depot maintenance, metal parts, such as electronic enclosures and connectors, could be replaced with thermoplastic parts.

V. Conclusions and Recommendations

Review

This research was aimed at analyzing the feasibility and application of the parts replication program to alleviate the high cost of contracting out the manufacturing of small lots of replacement parts.

The literature review and interviews showed that thermoplastic injection molded parts are a viable option for replacing certain metal parts on an airplane. These parts were limited to nonstructural applications such as electronic enclosures and connectors. They also showed the advantages of thermoplastic parts versus metal. The thermoplastic parts were more easily fabricated, more durable, corrosion resistant and less costly.

The interviews with members of the parts replication program at the Sacramento ALC also revealed the use of state of the art injection molding equipment. This equipment included the CAD system for designing parts and molds, the master link to control the numerically controlled milling machines used in making the molds, the 1500-ton injection molder and its process control system. Together this equipment helps make the parts replication program a high technology manufacturing system. Although the parts replication equipment is not a total flexible manufacturing system because the segmented molds require the segments to be extracted by hand and then reset for the next part, the labor cost is still less expensive then building a complex single-piece mold.

Finally, the parts replication program will not alter the flow of planes going through depot maintenance. It is not seen by the members of the program as a means to build parts quickly for a plane going through depot maintenance. The time required to test new thermoplastic parts prohibits quickly replacing a part that is out of stock or nor longer made with an injection molded part.

This chapter describes the conclusions and recommendations drawn from the results of the literature review and interviews. It also contains a brief description of two new emerging thermoplastic manufacturing techniques which may hold promise for making improved airplane parts.

Discussion

This concluding discussion summarizes the research findings and attempts to establish the significance of the parts replication program.

Chris Frank, who is currently managing the program, stated that his shop will need to produce at least a 1000 parts in order to amortize the cost of designing a part, building the mold, and manufacturing the part. He believes that he small batches of parts that his shop will produce will be between 1,000 to 10,000 units (Frank, 1987).

Tom Steward, manager of manufacturing at Cincinnati Milacron, was surprised that the parts replication program had purchased a 1500-ton molder. He explained that firms in the injection molding industry only purchase such large machines after they know exactly what they are going to produce. The firms then amortize the cost of the machine, approximately $800,000, over millions of parts (Steward, 1987). In contrast, the parts replication program had no specific parts tested and ready for production prior to buying their equipment (Frank, 1987). Chris Frank noted that at the inception of the parts replication program the primary candidates for injection molding were the overwing fairing on the F-111 and a leading edge panel on both the A-10 and F-111. Over the time period between inception and the actual equipment being ready for use, these candidates were sourced out to other contractors by the item managers. In order to find other parts that could be injected molded, the program sent out an injection molding candidate part questionnaire to the ALC's (See Appx A). The two parts currently being prototyped at the Sacramento facility are the enclosure for the ALE 40 chaff flare system and the fin for the 600 gallon drop tank used on the F-111. The enclosure is expected to be produced at $60 a piece versus the current price of $250. The enclosure is scheduled to be finished with testing by October 1987. The tank fin is expected to cost $250 versus the current purchase price of $2500. The tank fin is still in the prototype stage with no date established for flight testing. Mr. Frank expects the program to be in full swing and manufacturing parts within the next two years (Frank, 1987). Mr. Frank further explained that a large 1500 ton injection molder was warranted because the parts that were initially proposed required such a machine to handle the large molds. He also stated that no firm that owned a 1500-ton injection molder would be willing to allow the Air Force to use their machine for experimentation (Frank, 1987).

The researcher believes that the development of the parts replication program is contrary to established injection molding industry standards. As Mr. Steward described, firms purchase injection molders only after they've established exactly what products they are going to manufacture. The parts replication program purchased equipment without knowing the parts they were going to produce. Because of this fact, a cost anlaysis of the program seems impossible. Since the program is in its incipient phase and not actually manufacturing parts, establishing a break-even point or pay back period seems impractical at this time. Also establishing accurate cost savings information for the parts being replicated is nearly impossible without being in the manufacturing stage and knowing production costs.

Although a cost analysis is impractical at this time, the researcher does find merit in the parts replication program. The experimentation and manufacturing expertise gained by members of the program will give the Air Force a group experienced in injection molded thermoplastics. This group will most likely continue to find other areas in which thermoplastic injection molded parts may be used on an airplane. The group also proposes to extol the inherent advantages of thermoplastic parts over metal.

Overall, the parts replication program holds a promising alternative to current manufacturing techniques. It also has the potential to save four to ten fold the cost of current parts that can be replicated using thermoplastics.

Recommendations

As the parts replication program matures, further research will be needed to develop an accurate cost analysis of the program. In addition, technological developments within the injection molded thermoplastic industry are progressing rapidly. Further research will be needed to analyze these developments for application in the manufacturing of airplane parts.

During the course of this research two emerging thermoplastic manufacturing techniques were discussed by experts. These new techniques may provide information for future research in applying them to the manufacturing of airplane parts.

The first manufacturing technique discussed was tape-laying. According to Robert C. Harper, a research supervisor at Cincinnati Milacron, tape-laying is a process in which long continuous fibers of thermoplastic are laid upon each other at various angles. The layers are built up much like plywood. By heating the tape, it laminates itself to the previous layer. Also by laying the tape at 30 degree angles to each other, the final panel of thermoplastic provides strength in all directions. This process provides a panel that has been found to be ten times stronger than aluminum at two-thirds the weight. Once the panel has been made, it can be reshaped into various parts by using a heat press and mold (Harper, 1987).

The second manufacturing technique was explained by Captain Mike Fortson, an advanced composite engineer at AFWAL. This technique also uses long continuous fibers. The thermoplastic resin and carbon material are spun into fibers which are then woven into a fabric. The thermoplastic/carbon fabrics can be laid upon each other. The fabric is drapable as opposed to the stiff tape-laying panel. The fabric can be draped over complex angles of a mold then a heat press applied to make a solid part. Captain Fortson described a final part made out of this fabric as being very strong. He stated that this technique allowed engineers to design strength into a part for various stress angles. This can not be done with metals. He also explained that the thermoplastic part would not delaminate and is extremely ductile. If the material is damaged, a dent or ding would be visible which signals the need for inspection. Damage is localized on the part if impacted and the part would be able to withstand higher impacts than metals (Fortson, 1987).

Both of these techniques take advantage of the strength inherent in long continuous fibers. They also allow engineers to design for specific stress loads on a part which can not be done with metals. Further research needs to be conducted to find applications of these techniques for manufacturing airplane parts.

Summary

This chapter concludes the study by bringing together the analytic results from Chapter IV and the more subjective responses from experts to arrive at answers to the specific problem. This research project is not intended as an end in itself, but should be considered as part of an ongoing effort to better understand the implications and applications of the parts replication program.

Injection Molding Candidate Part Questionnaire

Current Part Information

Failure mode of part (fatique, corrosion, etc.) ______________________

____

Material ______________________________________

Life ____

Useage rate ___________________________________

Order quanity _________________________________

Part cost _____________________________________

Removal and replacement cost __________________

Loading Conditions

Type of load __________________________________

Duration _____________________________________

Impact present ________________________________

Environmental Conditions

Working temperature ___________________________

Highest temperature subjected to, and for how long ____________

____

Ultraviolet light exposure (direct sunlight) ____________

To which chemicals is the part exposed ____________

____

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After graduating from the USAF Academy in May 1980, he attended navigator training. Captain Shalz was then assigned to the 20th Military Airlift Wing in Charleston, SC as a navigator on the C-141B. There he served as a squadron executive officer and instructor navigator. In April 1984 Captain Shalz became Chief of Plans/Intelligence officer for the elite Special Operations Division of the 437th Military Airlift Wing. Before coming to the Air Force Institute of Technology, he was an instructor at Mather Air Force Base, CA for navigator training. Upon graduation, Captain Shalz will depart to Los Angeles where he will join the other suntanned members of Space Division.

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19. ABSTRACT

The purpose of this study was to examine the feasibility and application of Air Force Logistics Command's parts replication program to alleviate the high cost of contracting out the manufacturing of replacement parts. The program uses thermoplastic injection molded parts as replacements for metal parts.

The study found that the program had state of the art injection molding equipment. This included Computer Aided Design (CAD) equipment to design parts and molds and Computer Aided Manufacturing (CAM) equipment to help produce molds. Additionally, the process control system on the injection molder helped the operator control molding paraments and helped diagnose any problems during the molding process. Secondly, the study found that injection molded thermoplastic parts can replace certain metal parts on an airplane. However, these applications were limited to nonstructural parts. The inherent characteristics of thermoplastics gave them an advantage over metals. They were more easily fabricated using injection molding, more durable, corrosion resistant, and cost less to manufacture than current metal parts.

In addition, the study found the parts replication program at the Sacramento Air Logistic Center (ALC) to be in its incipient phase. Currently, research is being conducted by the program on two parts, an enclosure for the ALE 40 chaff dispenser system and a fin for the 600 gallon drop tank used on the F-111. The program has also sent out a parts questionnaire to the other ALC's in an attempt to find other parts which can be replaced with thermoplastics.

Since the program is not currently manufacturing parts, actual production costs were unknown. Without this information, it was impossible to do a cost analysis of the program. As the program matures, further research is recommended to establish a cost analysis when the program is in its manufacturing stage.